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THE BROADER ASPECTS OF RESEARCH IN TERRESTRIAL MAGNETISM[1]

IT has become the custom—fortunately or unfortunately as the case may be—that the retiring presiding officers talk on a particular subject, announced some time ahead, instead of being permitted to indulge in merely general reviews, as is the case in some organizations. Before I had a chance to think definitely on the matter, request was received from the permanent secretary four months ago that the title be furnished him at the earliest possible moment.

My original desire was to have the opportunity of talking to you on some more general subject than the one I have finally chosen. The topic, magnetism in general—a review of our fundamental ideas, the status of researches on the question "What is a Magnet"—appealed to me strongly. In connection with my researches in terrestrial magnetism, I have naturally been obliged to look occasionally out beyond and raise questions on the general problem of magnetism. When not only the permanent secretary, but the secretary of this section and the present chairman, began to make inquiries as to my subject, I had to settle upon something. And when I turned to your chairman for assistance in coming to a decision, and submitted to him several topics, *e. g.*, "The General Problem of Magnetism," "The Physical Bearing of Problems of Terrestrial Magnetism," etc., he indicated his preference for one relating

[1] Address as retiring vice-president and chairman of Section B (Physics), American Association for the Advancement of Science, given at Minneapolis, Minn., December 29, 1910.

to terrestrial magnetism, for he said, "A man usually talks best on the subject he knows best." Note the diplomatic and graceful manner in which he intimated to me that I might possibly know a little more as to the earth's magnetism than of magnetism in general. However, since magnetism is one of his own particular fields of research, may we not hope that he will decide to talk to us about this broad subject himself when he reaches the retiring age?

In fact, I am quite ready to confess ignorance of the most absolute kind on the whole subject of magnetism, terrestrial as well as general. And I am all the more willing to do so because I find myself in excellent company. Was it not von Helmholtz who characterized "magnetism as the most puzzling of natural forces"? Did not Rowland say that next to gravity, the greatest problem is that of terrestrial magnetism? Was it Lorentz who said that our ignorance in magnetism is the disgrace of modern physics, or words to that effect?

On the whole, it perhaps does seem best that one should talk, as far as he can, on an occasion like this, concerning a subject from his own directly acquired knowledge. As a retiring president of the British Association some years ago aptly said, when apologizing for confining himself chiefly to his own immediate subjects instead of attempting a complete general survey of the progress of science: "Partial views are better than inexact ones; and provision is made for their completion in the annual change of your officer."

I must take it for granted that I owed the honor of my election as vice-president and chairman of this flourishing section, two years ago, to the fact that it has been my privilege to contribute something towards the stock of our knowledge of the earth's magnetism. I may therefore assume that you want me in the first instance to "reveal myself in my own subject." I will then only ask one favor of you in return, that you allow me to omit more or less wearisome details and deal to-day only with some of the broader aspects of terrestrial magnetic research.

Professor Arthur Schuster, during his visit to Washington last September, one day remarked jokingly to the speaker, "I am not quite sure whether it has really been best to have a special journal on terrestrial magnetism for gathering in the chief papers. For when no such organ existed physicists *saw*, at least occasionally, an article on the subject in their journals, even if they did not read it." The presumption evidently was that physicists nowadays have less opportunity for imbibing knowledge on terrestrial magnetism and kindred subjects.

So then, if I, a *terrestrial* magnetician, may be pardoned for knowing but little of magnetism, or, for that matter, of physics in general, possibly the *pure* magnetician or the pure physicist would likewise in turn have a valid right to ignorance in terrestrial magnetism and cosmical physics, were it not for the contradictory fact that he is often found to be the author of our encyclopædia articles on these very topics. His wisdom in these particular fields appears to be gained in that wholesome and unwearisome manner employed by Herbert Spencer, who "never began by attempting to learn what had already been said." "All my life," said he, "I have been a thinker and not a reader, being able to say with Hobbes that 'if I had read as much as other men, I should know as little as they.' "

We are to spend a few moments together to-day in looking at some of the broader aspects of physical research in a field that, with justice, many of you may look upon

as an exceedingly special and restricted one and perhaps even question its right to be classed among the physical sciences. And yet this subject of the "earth's magnetism," which may consider itself fortunate if a brief section is devoted to it in the average text-book of physics, is itself so broad and so extensive that I know of no single investigator who could to-day be regarded as equally eminent in all its various branches and sub-branches. To be a master in terrestrial magnetic research requires the most intimate knowledge of several of the so-called fundamental sciences, especially of mathematics, physics and geology, with some knowledge of astronomy, meteorology, chemistry and geography besides. "The field of investigation," says Maxwell, "into which we are introduced by the study of terrestrial magnetism, is as profound as it is extensive."

MAGNETIC DISTURBANCES

Instead of beginning with the phenomena usually chosen to illustrate the earth's magnetism, let us begin with one of the irregular, more or less spasmodic manifestations—one of the so-called "abnormal features"—the earth's "magnetic storms" as they were termed by Humboldt. Because of the troublesome nature of magnetic disturbances, when one is dealing with a phenomenon like the diurnal variation, for example, various magneticians for nearly three quarters of a century have been seeking some logical method of deciding just at what point a disturbance begins—in brief, how large must be the fluctuation in a magnetic element to be classed and eliminated as a "disturbance." Various rules have been set up, but none has found general acceptance.

There was a time when it was thought that, by mere inspection of the photographic record of the variations of a magnetic element during the day, it was possible to say whether that particular day was disturbed or not; and so arose in Great Britain, for example, what are called the "astronomer royal's five quiet days during the month." Through Airy's initiative, the first English magnetic observatory was established at the Greenwich Observatory during that period of intense magnetic activity which prevailed in the first half of the last century—during the days of Humboldt and Gauss. The honor of deciding on the five quietest days in any particular month from which the "normal" diurnal variation may be deduced, has therefore been accorded to the head of the Greenwich Observatory; these days are selected by him, or more likely by his magnetic assistant, from a mere inspection of the photo-magnetograms. However, it has been found that these supposedly quiet days may themselves be subject to a more or less constant disturbance which, prevailing throughout the day, serves to elevate or depress the entire curve and hence does not reveal itself in superposed serrations or "eruptions." Or the disturbances may follow somewhat the same course as the diurnal variation itself, and hence again not be revealed by mere inspection, but serve mainly to increase or decrease the diurnal range.

Van Bemmelen and Chree have also found that these supposedly quiet days are subject to a non-cyclic effect similar to that shown by other days. I recall that during my first magnetic survey—that of Maryland, 1896–99—there were months when a searching examination of the photographic records of the magnetic observatories showed that there was hardly a day out of a whole month without some kind of irregularity.

It is then evident that a phenomenon which occurs so frequently and which in

fact appears ever to be present in some degree, at least, in the prevailing magnetic condition of the earth, is hardly to be treated as an outcast or as an "abnormal" feature. I very much question whether it will ever be possible to set up any rules which will separate scientifically the supposedly abnormal from the supposedly normal fluctuations of the earth's magnetism. I am rather inclined to believe that as progress is made there will be fewer and fewer attempts in this direction. On the contrary, *instead of eliminating a disturbance because it will not fit in with a particular mold or pattern, we shall learn that knowledge is mostly to be advanced by retaining it.*

In order to have something definite with which to deal I am going to ask you to confine your attention to-day chiefly to the abruptly beginning magnetic disturbances, bearing in mind, however, that not all magnetic storms begin thus. The first interesting question which arises regarding these sudden storms is whether, if referred to universal time—say, Greenwich mean time—they begin, within the limits of measurement, at the very same instant over the entire globe, or at least over a great portion of it. Up to the beginning of this year it was, indeed, generally believed that there was no measurable interval between the times of beginning of sudden disturbances even for very distant stations. The opinion was that the time differences which were revealed were only apparent ones, not real—that, if there were no errors of observation, they would vanish. So the belief arose that it might be possible to find the longitude between two distant stations by determining with the utmost accuracy the local mean times of identical perturbations, for, be it remembered, even the very smallest of these find their counterparts frequently at very remote stations.

A magnetic effect propagated with the velocity of electromagnetic waves would require but one eighth of a second to pass completely around the earth; if with the speed of a cathode ray, the circuit time would be on the order of a half or three fourths of a second. If then magnetic disturbances were propagated over the earth with such velocities, our present instrumental means would not suffice to detect any time differences between stations, though on opposite sides of the earth. If, however, differences of whole minutes are found instead of only fractions of a second, it will at once be seen that a most valuable clue has been obtained towards disclosing the nature and origin of our magnetic storms. It is my belief, furthermore, that *a long step forward will have been taken towards the solution of the origin of the earth's magnetism when once we have found out what causes it to vary*—what it is that can derange the magnetization of our entire planet to the extent of ten to twenty per cent. in the brief interval of a quarter of an hour, as actually occurred during the magnetic storm of September 25, 1909, the most notable of which we have any record. Referring to changes in the earth's magnetism, insignificant alongside of those just mentioned, viz., the secular changes, which only reach a comparable amount when integrated over a period of several centuries, Maxwell says: "When we consider that the intensity of the magnetization of the great globe of the earth is quite comparable with that which we produce with much difficulty in our steel magnets, these immense changes in so large a body force us to conclude that we are not yet acquainted with one of the most powerful agents in nature."

I would now like to call your attention to some interesting facts found with regard to 38 of these sudden disturbances which

occurred during the years 1882–1909. No. 1 of these is the unique magnetic disturbance of May 8, 1902, which, as far as can be ascertained, occurred simultaneously with the destructive eruption of Mont Pelé. On account of this interesting coincidence the records of twenty-five observatories in different parts of the world were collected and studied in my office. When the various scalings of the time of beginning of the disturbance were put together, they appeared to increase to the east, the effect apparently having been recorded first in Europe, next in Asia and last in America. The speed of progression was such that a continuous circuit of the earth around a great circle would require nearly 4 minutes, or in other words, the velocity was on the order of 100 miles per second or only about one two-thousandth that of light.

No. 2—the disturbance of January 26, 1903—was one investigated by the eminent physicist-magnetician Birkeland, the author of the cathode ray theory of magnetic disturbances. For this again an easterly progression, on the same order as for No. 1, was found.

Next, Nos. 3–19 are 17 storms between 1882–89 which were investigated by William Ellis, who was for a half-century in charge of the magnetic work at Greenwich.

The nineteen cases thus far mentioned showed a remarkable consistency in the direction in which the times increased, viz., to the eastward, only one sixth showing the reverse direction.

In order to test this result further with the aid of the best data immediately available, Mr. R. L. Faris, Inspector of Magnetic Work of the United States Coast and Geodetic Survey, undertook, at my request, a special examination of fifteen sudden storms between 1906 and 1909. He had to restrict himself for the time being to the five magnetic observatories belonging to the United States, viz., Cheltenham (Maryland), Porto Rico, Baldwin (Kansas), Sitka and Honolulu, which extend over about one quadrant of the earth. Mr. Faris scaled the times of beginning with every possible care; he estimated that the error of measurement was about one half minute and certainly not over one minute. Yet the individual observatories differed by quantities ranging from 1.1 to 6.7 minutes! Here again, for 10 out of 15 cases, the direction of progression, over the limited portion of the earth embraced, was eastward, and for only one third was it westward.

The next four cases are some tiny preliminary disturbances preceding larger ones, investigated by the director of the Zi-ka-wei Magnetic Observatory, Father J. de Moidrey, and by Mr. Faris; for two of these the direction of progression was east, and for two, west.

Summarizing—for 28 out of the 38 cases the times of beginning increased eastward and for but 10, or about one fourth, the increase was in the reverse direction. The following conclusion was accordingly drawn:

Magnetic storms do not begin at precisely the same instant all over the earth. The abruptly beginning ones, in which the effects are in general small, appear to progress over the earth more often eastward though also at times westward, at a speed of about 100 to 200 kilometers per second, so that if a complete circuit of the earth were made it would require, on the average, between 7 and 3 minutes.

DIRECTION OF MOTION OF MAGNETIC DISTURBANCES

If it is a fact that magnetic disturbances are propagated more decidedly in one direction than another and that they dif-

fer, in this respect, from seismic disturbances which proceed in all directions from the center of disturbance, then a harmonic analysis of the disturbance effects should furnish further evidence. A definite electric or magnetic system must be accompanied by equally definite effects on our suspended magnetic needles. Knowing the latter, we ought, in turn, to be able to determine the general character, at least, of the producing system.

The beginning of the disturbance of May 8, 1902, may be taken as typical of the general type of perturbation thus far considered, viz., an increase in the horizontal intensity over the whole, or at least the greater part, of the earth, and a decrease in the vertical intensity in the northern magnetic hemisphere, and an increase in the southern. Applying a mathematical analysis, it is found that the system of forces which could produce the observed disturbance was a two-fold one—the first, the stronger, consisted of a set of electric currents in the upper regions, circulating eastward around the earth, if negative currents, and the reverse, if positive ones; the second, a weaker system, contained within the earth and possessing the characteristics not of an induced electric system, but of directly induced magnetism of the same sign as that of the earth's own field.

Please note that according to this analysis the disturbance system is chiefly an overhead set of currents proceeding, if negative ones, in an eastward direction around the earth—but this, in fact, is the direction in which the recorded times of beginning of the disturbance were found, in general, to progress. One method of investigation thus independently supports the other.

How may we suppose that negative electric currents are brought about in the regions above us which could thus affect our magnetic needles? If the progression in the times of beginning of the effect may be interpreted as meaning that, whatever the cause, it is moving with a velocity measured by the differences in the times at distant points on the earth, then the resulting velocities are on the order of about one two-thousandth that of electromagnetic waves, or about one four-hundredth that of cathode rays. The question immediately arises—May not the required overhead negative electric currents be brought about by rapidly moving electric charges, whose accompanying magnetic perturbations are but an exhibition of the Rowland effect on a scale far transcending any laboratory experiment within the power of man? We may be dealing with ionic charges set in motion, as the result of a releasing action from some quarter, by sources of energy already existent in the regions above us, whence currents arise—

"Of power to wheedle
From its loved north the subtle needle,"

as Maxwell said with regard to the convection currents, which "that doughty Knight, Rowland of Troy, did obtain."

Now before indulging in a bit of scientific imagination, let me caution you to distinguish carefully between what is fact and what is hypothesis. The results communicated respecting the differences and progression in the times at which sudden perturbations occur, as well as those derived from the mathematical analysis of the recorded effects, are independent of theory. You may not agree with me in any hypothesis which I may attempt to establish as to the cause of magnetic disturbances and the *modus operandi,* but please remember that the facts remain, however difficult may be the problems which they present.

HYPOTHESIS OF IONIC CURRENTS

According to the measurements of Rutherford and Zeleny, the average total ionic velocity for dry air at the earth's surface and an electromotive force of one volt per centimeter, is 3.2 cm./sec. At this rate it would take forty years to encircle the earth. Putting together all the facts of laboratory experiments at present available to me, including the work carried out at the laboratory[2] here by Zeleny and Kovarik, a provisional calculation appears to show that, for the atmospheric pressure prevailing at about the height of 75 kilometers, the ionic velocity would be of the order required for a circuit of the earth in about four minutes—hence, of the order found above to correspond with progression of the observed times of beginning of a sudden magnetic perturbation.

A mathematical analysis of the magnetic observations made at various points on the earth's surface has revealed the existence of a definite system of atmospheric electric currents whose magnetic effects are of sufficient magnitude to require their being taken into account when determining the so-called magnetic constants of the earth. Now if the atmosphere is made more conducting at any point, as the result, for example, of the ionizing effect from solar radiations, an extra current will be started and set in motion by the electromotive force existing at that point. The direction finally followed by the extra current will, however, not depend alone upon the prevalent electromotive force, but also upon the deflecting effect of the earth's magnetic field and of the earth's rotation on the electric carriers, and doubtless upon a variety of other conditions.

If a negative ion is set in motion at a given altitude in an eastward direction, the deflecting effect of the earth's magnetic field will be to bring it down closer and closer to the earth. But the ionic velocity decreases with decrease of altitude, hence the magnetic effect produced by the moving charge on a needle at the earth's surface will begin later and later, as the charge travels eastward. If, on the other hand, the negative ion starts westward around our planet, then the deflecting effect of the earth's magnetic field would be to make the charge move higher and higher and, hence, faster and faster. We might thus possibly have the following state of things: Due to some cause, electric charges are set in motion in every direction from a certain point overhead. Those with an easterly component of motion have their velocities checked in the manner just described, whereas those with a westerly component are made to move faster, so that for two stations, one east and one west, the magnetic effect is recorded later at the east station. This deduction you will observe would correspond with that actually found for the vast majority of the 38 disturbances above treated. In brief, the deflecting effect of our own magnetic field would be favorable towards the maintenance of easterly progressing negative ions, since by bringing them closer to the earth their effect is increased, and unfavorable for the westerly ones since they are made to move farther and farther away from the earth. Whether it is due to this fact that a sudden disturbance progresses more often to the east than to the west is an interesting query.

THE PECULIAR MAGNETIC DISTURBANCES OF DECEMBER 29–31, 1908

I want to make you acquainted next with another set of most instructive magnetic disturbances which differs from the kind previously considered in several important

[2] The Physical Laboratory of the University of Minnesota.

respects. The effect of the previous type of disturbance was to superpose, on the earth's existing magnetic field, a subordinate magnetic system possessing essentially the same characteristics as the primary field, differing from it only in degree—in brief it *increased* momentarily the earth's magnetization, and hence might be termed a "positive magnetic perturbation." It was also a world-field—its effects were recorded all over the earth.

But now we are to have examples of a "negative magnetic perturbation," whose effect is to superpose a magnetic field opposite to that of the earth, in short, diminish the earth's prevalent magnetization, and whose area of action is a comparatively restricted one. These perturbations were not felt over the whole earth within a few minutes of the same absolute time; instead the intervals between the recurrences in different parts of the earth were to be measured by hours and even a day.

Attention was first called to these peculiar magnetic disturbances by D. L. Hazard, of the United States Coast and Geodetic Survey, and recently R. L. Faris, of the same organization, has collected information regarding them from a large number of observatories over the globe. These disturbances did not extend much over one half hour and occurred on a practically undisturbed day. The maximum deflection in the horizontal component of the earth's magnetic intensity amounted to about one five-hundredth part. The complete data will be found given by Mr. Faris in the March, 1911, issue of *Terrestrial Magnetism and Atmospheric Electricity*. I am indebted to him for the privilege of making use of his data in advance of publication.

Four times out of eight cases the region over which the disturbance prevailed was the American continent and the Pacific Ocean as far as Honolulu; in one case the region was limited to the Atlantic Ocean and the American continent; twice it occured in eastern Asia and but once in Europe. Hence, had we been obliged to rely solely upon the magnetic records from the region of the earth, Europe, where the majority of magnetic observatories exist (about 20), we should have had to report but one magnetic disturbance between December 29 and 31, 1908, instead of actually eight. No fact known to me illustrates more convincingly than this the folly of increasing greatly the number of magnetic institutions in the same region of the globe. It also proves that, when dealing with general terrestrial magnetic phenomena, no such weight can be attached to the combined testimony of the European observatories as has heretofore been the custom. To give weight, as is frequently done, according to the *number* of existing magnetic institutions in any one region leads to totally erroneous results. We are reminded of the wise words of Joseph Henry which, though uttered in a different connection, apply with special force here, viz., "*Votes in science should not be counted, but weighed.*"

Now why is it that these particular magnetic perturbations were confined each time to but a portion of the globe? The intervals in time between the successive occurrences range from $1^h\,5^m$ to $24^h\,21^m$, whereas the apparent velocities shown over the area covered at any particular appearance of the disturbance is on the order of the quantities as previously found for the first type of disturbance considered. The question immediately arises, therefore, as to whether we are dealing here with *two* velocities. Have we, for example, a vortex consisting of very rapidly moving electrical charges, an earth-spot, as it were, the vortex as a whole, however, moving

comparatively slowly over the earth? Or, are we to suppose that at each recurrence the disturbance was formed anew? No matter what view we adopt, it is evident that we are about to find out another important fact.

Determining the local mean time of the extreme stations at which the disturbance was recorded whenever it occurred, it is immediately seen that *only the observatories in the daylight zone were affected.* At those observatories where the local time was somewhere between 4 P.M. and 6 A.M., no effect was obtained. Hence, the conclusion is inevitable that *solar radiations of some kind must have played an important part in the production of these disturbances.* There were at the time on the sun's visible disk some peculiarly eruptive spots which may have to be held responsible for the peculiar magnetic disturbances.

A mathematical analysis of this type of magnetic perturbation is at present under way, but it has already become sufficiently evident that we are dealing here with a much more complex system than in our first type.

GENERAL DEDUCTIONS RESPECTING MAGNETIC DISTURBANCES

From the two types of disturbances considered it has been found that not only may our most sudden magnetic disturbances begin at measurably different times for various points on the earth's surface, but also that magnetic perturbations may even be confined to but a very limited portion of the globe.

The possibility of a regional magnetic disturbance was foretold with the aid of a law which I found to hold regarding magnetic changes in general:

"*Alterations in the earth's magnetic condition, whatever their nature or origin may be, appear to be distributed over the globe according to a law profoundly dependent upon that governing the distribution of the earth's own primary magnetic forces.*"

The prediction made on the basis of this law last spring, before the facts had become known respecting the disturbances mentioned, was as follows:

> I confidently expect, as soon as a complete analysis has been made of magnetic disturbances covering the greater portion of the earth, it will be found, that the disturbance field, in general, presents all the characteristics of the terrestrial, primary one, the disturbances will themselves reveal effects from terrestrial, continental, regional and even local causes (earth currents, for example, whose path and intensity depend upon local character of soil, etc.).

Were this the place, I should like the privilege of setting before you the full import of this law. How, for example, we find characteristics in the magnetic fields composing the so-called permanent magnetization of the earth analogous to those which represent the systems producing the time variations. Suffice it to say that, if we were to establish a mathematical expression for the respective systems involved, the same terms would appear in the space variations as in those of the time. We might tersely put it thus: "*In terrestrial magnetism space and time are often relatively interchangeable.*"

Before leaving the subject of magnetic disturbances let me point out to you two or three additional interesting facts which may serve to guide us in our study of causes.

It is the usual custom to exhibit the dependency of the fluctuations in the earth's magnetic condition during a sunspot cycle by means of changes in certain particular magnetic elements, as for example, the change in the amplitude of the diurnal variation during the sunspot cycle, this amplitude increasing with increased solar

activity. If, however, we make use of a more direct physical quantity, viz., the earth's magnetic moment, or let us say intensity of magnetization per unit volume, then we find that, *in general, during a sun-spot cycle the earth's magnetization decreases with increased solar activity.* In brief, on the average, the effect of magnetic perturbations is to superpose on the earth's magnetic field a magnetization opposite to that of its own, and hence the effect is one of demagnetization. The quantity involved is on the order of that found some years ago when I raised the question as to whether the earth is gaining or losing magnetism.

This question was attacked in two different ways; first, use was made of the existing magnetic charts between 1840 and 1885; secondly, freshly accumulated data between the years 1890 and 1900 were utilized. Both investigations led to the same result, viz., that *the earth's magnetic moment is at present being diminished by about one twenty-four hundredth part annually.* Now, if the terrestrial magnetician were permitted to make the same apparently violent extrapolation as is indulged in by the radio-physicist, he would find that, at the present rate of decrease, the earth's magnetic moment will have dwindled to one half of its present value in about 1,660 years from now. Note that this period is practically the same as that of radium decay—probably a mere coincidence!

We may make use of magnetic perturbations in another way, mainly, to get some idea of the *earth's magnetic permeability.* I have already pointed out above that when analyzing the effects of the magnetic disturbance of May 8, 1902, it was found that there were two systems involved, one an external one composed of overhead electric currents, and the other, an internal one having the characteristics of directly induced magnetism. If we suppose that the second system is the result of the first, then the ratio of the potentials of the two systems will give us the differential change in the earth's magnetic permeability. Various calculations of this kind are under way.

One of the most important bearings of the facts above set forth regarding magnetic disturbances pertains to the slow, progressive changes to which the earth's magnetization is subject—secular changes. It has already been hinted above that these *secular changes can not be explained simply by a change in the direction of the axis of magnetization, but likewise imply changes in the intensity of magnetization.* Respecting the latter, our result was that apparently the residual effect of a magnetic disturbance is a diminution of the intensity of magnetization, which may last for some period after the cessation of the disturbance, two months, for example, as occurred with respect to the notable magnetic storm of September 25, 1909. Whether the earth ever recovers completely from a magnetic disturbance is questionable.

Now, *as to the effect of magnetic disturbances on the axis of magnetization,* let me merely point out that if magnetic disturbances do actually in general progress over the earth more often in one direction than in the other, the mechanical effect is to be reckoned with. If the progression is generally eastward, as appears to be the case, then the mechanical effect of the overhead currents will be to increase the velocity of the earth's rotation or, failing to do that, which is more probable, the effect will be to cause a displacement of the earth's magnetic axis eastward. We thus have disclosed to us one of the several systems causing the secular variation of the earth's magnetism which was pointed out in 1904

as the result of my analysis of the systems causing the secular variation.

The principal system, however, involved in the production of the secular variation is still to be revealed, and a promising line of inquiry, at present in progress, is the concomitant study of the laws followed by the secular variation and the lunar diurnal variation of the earth's magnetism; I have found that both follow remarkably similar laws in their distribution over the earth. It might also be mentioned here that owing to the non-commensurability in the periods of the solar-diurnal and the lunar-diurnal variations, there is an outstanding daily residual of the right magnitude for the production of the secular variation.

Sufficient has been given to show how important and fruitful is the study of the "abnormal" features of the earth's magnetism. It seems probable that we shall learn more from a close investigation of magnetic disturbances—of the irregular phenomena—than of the normal and regular features. In any event we find that the "abnormal" is such an intimate part of the supposedly "normal" that it seems unwise really to make a separation. We fully endorse the view of Schuster when he says:

> Outbreaks of magnetic disturbances, affecting sometimes the whole of the earth simultaneously, may be explained by the sudden local changes of conductivity which may extend through restricted or extensive portions of the atmosphere. I have shown in another place that the energy involved in a great magnetic storm is so considerable that we can only think of the earth's rotational energy as the source from which it ultimately is drawn.

According to the views above set forth, the various manifestations of solar activity, sunspots, protuberances, etc., are not the direct but the indirect cause of the earth's magnetic storms. Their effect appears to be more in the nature of a releasing or "trigger" action, setting in operation electric forces already in existence in the upper regions of the atmosphere; terrestrial sources, in reality, however, supply the energy required for the magnetic storm.

THE EARTH'S PERMANENT MAGNETIC FIELD

Our studies began with magnetic disturbances, and we soon found that we were dealing with systems of forces remarkably similar to those composing the earth's permanent magnetic field. Given an existing electrical field in the upper regions, it follows at once, from our knowledge of the necessarily varying conductivity of the atmosphere resulting from solar radiations of various kinds, that this field must be an exceedingly variable one. First, it must be subject to a daily variation of an average normal kind corresponding to the average normal solar radiation, and superposed on this more or less spasmodic fluctuations, which represent the variability in the supply of the essentials in the solar radiations for producing the observed magnetic effects.

In this connection let me point out an interesting bit of evidence furnished during the time of the total solar eclipse which occurred in the United States in May, 1900. As the result of the special magnetic observations, made chiefly by the observers of the United States Coast and Geodetic Survey, a small magnetic perturbation revealed itself at each station along the belt from Georgia to Maryland. This perturbation did not begin according to absolute time nor according to local mean time, but bore a distinct relation to the time of passage of the shadow cone. It was thus shown that by the interposition of the moon between the sun and the earth, certain radiations were cut off as the result of which a magnetic fluctuation was produced. I recall that the late Professor Newcomb appeared rather skeptical as to

the possibility of a magnetic fluctuation due to such a cause until one day he put this query to me: "If a magnetic effect is produced when such a small body as the moon comes between the sun and the earth, why do we not have an effect every day owing to solar radiation being cut off from one half the earth by the other?" Professor Newcomb had momentarily forgotten that we do have a daily effect of the very kind he had in mind, viz., the diurnal variation, and when I pointed this out to him he appeared convinced as to the possibility of a magnetic effect likewise during a total solar eclipse. I have shown that the magnetic effect during a total solar eclipse is precisely similar to that of the diurnal variation, differing from it only in degree and that the amplitudes of the respective oscillations are in direct proportion to the areas of the interposing discs.

Please recall also that in the second type of disturbance above treated, viz., those of December 29–31, 1908, we had further evidence of perturbations occurring only in the daylight zone; the inhabitants on the other side of the earth did not experience the perturbations.

If then so much can be explained or, let us say, suggested, on the supposition of an existing primary electric field in the region above us, then it behooves us to do our utmost to find out all we can as soon as possible regarding this field. And here is where the great value of the extensive magnetic operations of the Carnegie Institution of Washington will be demonstrated, for the precise characteristics of that outside electric field can not be accurately determined until the completion of a general magnetic survey of the globe. When that has been accomplished, which we hope will be the case within the next five or ten years, then the constants, or rather the determining coefficients, can be derived for the various constituent portions of the earth's total magnetic field.

Before closing this section let me call to mind a fact that is frequently overlooked, that *our only cognizance of the earth's magnetic field is through its external lines of force*. Cut these out, and we would conclude, in accordance with our usual test, that the earth was not magnetized. But we might have closed magnetic systems within the earth similar to that of a magnetized ring. Such a ring, however strongly it may be magnetized, has no outside magnetic effect and if we had no previous knowledge of its internal magnetization, we would conclude from our usual experiments that it is non-magnetic. I know of no method of disclosing such magnetizations as that of the ring without producing some mechanical change in the ring itself. Accordingly, our knowledge of the earth's primary magnetism would be confined wholly to external effects, were it not for the fortunate fact of the variations continually caused in the earth's magnetism by outside forces. You will therefore see the point to my statement that, in my belief, *it is useless to attempt an explanation of the origin of the earth's magnetism until we have found out what causes it to vary.* Perhaps even then it may turn out that we shall have to be content with simply raising the question already put by Schuster whether "every rotating mass may not be a magnet."

In this connection let me record here an interesting fact which I found some years ago. If we determine the earth's magnetic axis and intensity of magnetization per unit volume separately for various parallels of latitude, then there is a distinct connection shown in the values of the constants involved with the speed of rotation of a particle on the parallel concerned.

A BROAD VIEW

I began my address by setting before you some of the results of research in a field which I am ready to acknowledge appears, as I have already said, a very restricted and special one. But as we progress we are continually forced to raise questions which go far beyond our specialty and touch at the very heart of matters in which we all take a common and lively interest.

The all-comprehensiveness of terrestrial magnetic phenomena makes us more than ever aware of the necessity of taking broad views and keeping our minds ever open and free so that we may receive and weigh the facts observed with the proper care and in the proper scientific spirit.

The terrestrial magnetician is continually having forced upon him the fact that the "axis of the universe does not stick out of his own back yard." He can not follow the example of his more fortunate brother, the geodesist, who, from careful measurements made over but a very limited portion of the earth can determine its figure with wonderful precision, the best possible demonstration of which we shall have today from the address of the retiring chairman of Section D. To the geodesist a mass of lead is the same as an equal mass of magnetic iron ore; not so, however, to the magnetician. Were he to attempt the determination of the position of the earth's magnetic axis and of the earth's magnetic moment from a series of extensive magnetic observations in the United States, he would obtain results totally different from those similarly derived for an area of equal size in some other part of the globe. So likewise, as we have found with respect to the earth's magnetic disturbances, five well distributed magnetic observatories can accomplish more, viewed from a general, terrestrial standpoint, than twenty of the best equipped magnetic observatories concentrated in but a limited portion of the earth, however civilized that portion may be.

Thus the student of magnetism has difficulties not encountered in geodesy, and he would appear to suffer under great disadvantages. Perhaps, however, the disadvantages under which he labors as regards one object may become a source of advantage in a totally different one; by the very fact that to the magnetician a lump of iron is different from a similar mass of lead he is enabled to draw certain conclusions with regard to the materials forming the earth, denied to the geodesist. One of our foremost geologists has predicted that our knowledge of the internal constitution of the earth is to be advanced primarily through terrestrial magnetism and seismology.

Beginning with Gauss and up to within comparatively a few years ago, it was believed that it would be possible to establish a mathematical expression having a limited number of coefficients which would represent the magnetic observations made over the earth's surface, if not entirely within an error of observation, certainly within an error of approximately the same order. However, as carefully conducted magnetic surveys become more extensive, it is becoming more and more evident that it is useless, for practical purposes, to establish such mathematical formulas. Were we, for example, to have magnetic data all around the globe at intervals of five degrees in latitude and longitude, hence at 72 points on a parallel, it would be possible to set up a formula which should represent absolutely the values at the points given, but even for this case the expression would involve so many unknowns as to make the computation practically prohibitive. And after all this labor had been accomplished, it would not be possible to obtain the mag-

netic elements between the five-degree points and within the accuracy attainable even by ocean magnetic work. In fact the outstanding residuals would be on the order of 10 to 100 times the error of observation. This inability to represent the earth's magnetic condition by means of a closed mathematical formula having a definite physical interpretation might again be looked upon as a disadvantage. I, however, am inclined to look upon it as an advantage; for we have thereby a definite proof of the fact that magnetic observations are sufficiently delicate to disclose all of the heterogeneities and irregularities in the constitution of our earth. Had we time we might profitably spend a few minutes in looking at the testimony which may be furnished the geologist in this respect by the magnetic needle.

In conclusion permit me to refer to an incident which occurred at the meeting of the British Association held at Bristol in 1837. Sir William Hamilton, attending the session of the Chemical section and getting into a quarrel with his chemical brethren, remarked: "The nearer all the sciences approach Section A (mathematics and physics), the nearer they would be to perfection." I would make but one slight alteration in this assertion, namely, that the nearer we all approach to mathematics and *cosmical* physics, the nearer we should be to perfection.

L. A. Bauer

The Carnegie Institution of Washington

CHARLES OTIS WHITMAN

Professor Charles Otis Whitman, head of the department of zoology of the University of Chicago, died of pneumonia after a brief illness on December 6, 1910. He was born in Woodstock, Maine, December 14, 1842. He received the degree of A.B. from Bowdoin College in 1868, and A.M. in 1871. From 1869 to 1872 he was principal of Westford Academy and in 1872 was teacher in the English High School of Boston. A few years later he was studying zoology with Leuckart in the University of Leipzig and received the degree of doctor of philosophy from this university in 1878. From 1880–81 he was professor of zoology in the University of Tokio, and in 1882 we find him studying at the Zoological Station of Naples. From 1883–85 he was assistant in the Zoological Laboratory of Harvard University and was then appointed Director of the Allis Lake Laboratory at Milwaukee (1886–89). He was then called to the charge of the department of zoology of the newly founded Clark University, and in 1892 he became head of the department of zoology in another newly founded university, the University of Chicago, which position he held until his death, being thus associated with the whole of the formative period of this institution. He was the first director of the Marine Biological Laboratory, from 1888 to 1908, and established the policy of the institution. He was founder and also editor of the *Journal of Morphology,* the *Biological Bulletin* and the Woods Hole series of Biological Lectures. He was the chief organizer of the American Morphological Society, now the American Society of Zoologists, and was its president for the first four years. He was also a devoted teacher of advanced students many of whom now occupy important academic positions in this country. He was a member of many scientific academies and societies, and received the honorary degrees of LL.D. from Nebraska in 1894 and Biol.D. from Clark University in 1909. Among the subjects that occupied him during a life of intense activity in biological research were: the embryology, morphology and natural history of leeches, the morphology of the Dicyemidæ, the embryology of the bony fishes; evolution of color characters in pigeons; natural history of pigeons; hybridization and heredity in pigeons; and studies in animal behavior.

Professor Whitman's life was devoted entirely to scholarly ideals of biological research